RESULTS OF MEDICAL AND BIOLOGICAL STUDIES PERFORMED DURING THE GEMINI AND APOLLO PROGRAMS: CHANGES IN THE WORKING CAPACITY OF THE ASTRONAUTS

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16. Abstract

A survey of the literature on the psychosensory reaction of the astronauts, the flight programs carried out by them, and the results of postflight examinations employing various tests has shown that some astronauts noticed symptoms of a decrease in working capacity during space flights. Some of the problems involved in the prevention of unfavorable influences of spaceflight factors on the human organism are discussed.

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RESULTS OF MEDICAL AND BIOLOGICAL STUDIES PERFORMED DURING THE GEMINI AND APOLLO PROGRAMS: CHANGES IN THE WORKING CAPACITY OF THE ASTRONAUTS

V. I. Kopanev and Ye. M. Yuganov

The problem of the working capacity of the astronauts was the subject of great interest on the part of researchers during space experiments. A number of parameters were investigated including: psychosensory reactions of the subjects, movement and orientation under conditions of altered gravitational magnitude; analysis of the execution of flight programs and especially during spacewalks and on the surface of the Moon; postflight examinations of the astronauts using various tests. /5*

The most valuable information on the psychosensory reactions of the astronauts were obtained in their own reports. Even during the very first space flights in the Mercury and Gemini programs, it was noted that during the state of weightlessness a sensation of "discomfort" arose which had to do with a lack of pressure of the back and seat of the chair on the human body. Something similar was felt by the crew members of the Apollo 7 and 11 spacecraft. They experienced sensations of heaviness of various objects and their clothing (Berry, 1970). The mechanism of such phenomena clearly has to do with changes in the kinetic sensations caused by elimination of the usual stimuli of the tactile mechanoreceptors which are normal under terrestrial conditions. In more serious cases, the astronauts complained of pain in the legs and lower part of the back (Berry, 1971, a, b). The reasons

*Numbers in the margin indicate pagination of original foreign text.

for these pains are still not known, but it may be assumed that they were caused by the posture which the astronauts assumed during sleep (the fetal position), so that the kinetic sensations were altered.

The majority of American astronauts who took part in the Gemini and Apollo space flights also experienced a sensation of heaviness of the head when they made a transition from g-forces to a state of weightlessness; this sensation of heaviness was similar to that which develops on Earth in human beings who hang head downward. The phenomenon was temporary in nature and did not produce any effects upon the spatial orientation of the astronauts (Berry, 1970, 1971, a, b). The explanations for these phenomena are rather contradictory. Some feel them to be the consequence of a redistribution of the blood, with a rush to the head (Berry, 1971 a), while others interpret it as a disruption of the system of operation of the analysors reflecting space, as a result of changes in afferentation from all of the mechano- /6 receptors and particularly the otolith portion of the vestibular apparatus (Yemel'yanov, Yuganov, 1962; Komendantov, Kopanev, 1962; Yemel'yanov, 1966; Gazenko, Gyurdzhian, 1967; Graybiel, 1968). Obviously, both points of view have some degree of justification, but the second is more likely. In their reports, the astronauts stated that the illusions become more intensive during rapid movements of the head, and that they were similar to the sensations which arise under the influence of the Coriolis forces (Sisakyan, Yazkovskiy, 1962, 1964; Molchanov, et al., 1970).

In many instances, astronauts who experienced illusory sensations during flight developed a space form of the state of motion sickness.

Thus, during the flight of Apollo 8, F. Borman experienced nausea and gastric pain. The other members of the crew also experienced some incapacitation. After taking tablets to prevent motion sickness, the astronauts felt better. The majority of specialists concluded that motion sickness was caused by the development of the side effects of the soporific, combined with reactions to excessively sharp movements of the head and trunk during the first hours of exposure to weightlessness. However, motion sickness was also observed in the astronaut R. Schweikert (Apollo 9). While wearing his spacesuit prior to transferring to the lunar module, he suffered an attack of vomiting which was repeated several hours later. According to the data of Berry (1971 a), six of twenty-seven astronauts in the Apollo program experienced unpleasant sensations in the stomach, while two suffered from nausea and vomiting. Although there are no direct indications regarding motion sickness in the other astronauts in the Gemini and Apollo projects, there are indirect data which indicate that the irritability of the vestibular centers was increased: after splashdown of the Gemini 3 crew, both astronauts felt dizzy, while V. Grissom was nauseated; although the Apollo 10 astronauts did not complain of motion sickness, they used Lomotil tablets to calm their stomach pains, and the contents of one of the fecal bags, in nature and odor, resembled vomited material with a pH of 2 (Dietlein, 1970); the astronaut D. Irwin (Apollo 15) experienced discomfort during the first three days of the flight: he felt heaviness in the head and stomach. It seemed to him that nausea and vomiting might arise in the event of rapid movement. As he said, after the five-day flight he experienced sensations of having his head tilted approximately 30°.

It is clear from the above that the problem of motion sickness is still a timely one for specialists working on space medicine in the U.S.A., as it is in the Soviet Union (Komendantov, Kopanev, 1962; Yuganov, 1965; Graybiel, 1968, 1971; Johnson, 1971). According to the reports of Young (1971), failure to take this problem into account, which was the case formerly among specialists and American astronauts, is not at fault at the present time. The reasons for the development of motion sickness have been discussed (considerable freedom of movement of the head and trunk during flight) and the astronauts have understood the necessity of preflight vestibular training. The problem of motion sickness is becoming more topical as time goes by, as scientist astronauts start taking part in flights; their statokinetic stability is probably lower on the average than that of professional pilots. This is totally in agreement with the statement of Berry (1973) who pointed out that the high vestibular stability of American astronauts was due to the nature of their training. In most cases, they were pilots with considerable flying experience who constantly improved on the latter in the course of medical and biological preparations for space flights. If nonprofessionals are to take part, another stability level must be set. The experience of the medical aspects of the second expedition aboard the Skylab orbital station, when the astronauts showed symptoms of motion sickness during the 5 — 7 days of their stay under weightless conditions, confirmed this view.

The physiological mechanisms of the development of motion sickness in space are quite complicated. It is felt that changes occur in the reciprocal interrelationships between the receptor formations of the otoliths and the semicircular canals during weightlessness (Khilov, 1969). Deafferentation of the otolith apparatus promotes inhibition of reflexes from the semicircular canals and increases their sensitivity to the effects of angular acceleration. Miller, et al. (1969) and Kolosov (1969) have found /7 that movements of the head under conditions of brief weightlessness usually lead to development of autonomic syndromes more than they do under conditions of terrestrial gravitation. Wunder (1969) suggests that nausea may be accompanied by unusual distribution of gases and fluids in various regions of the gastrointestinal tract. G. L. Komendantov and V. I. Kopanev (1962), V. V. Baranovskiy, et al. (1962), I. D. Pestov (1965), and other researchers have suggested a reflex theory, in which the principal role is ascribed to disturbances of afferent influences from the mechanoreceptors, ensuring spatial analysis and perception of gravitational effects.

In analyzing the data from space experiments, one is struck by the interesting report of Berry (1970 a) on the characteristics of the feeling of hunger which arises in the astronauts under conditions of weightlessness. They are similar to the sensations which arise under terrestrial conditions, but more rarely, although food was used to a lesser extent. The astronauts aboard the Gemini 4, who did not use up the 500 — 700 kcal alotted them on a daily basis (normal 2500 — 2600 kcal) did not suffer from hunger during flight, although they were very hungry after they landed. The member of one crew reported that the "expansion" of the stomach kept them from taking their normal amounts of food and drink. Obviously, the weightlessness condition had a definite influence upon the receptor apparatus of the interoceptive analysor.

Considerable attention was devoted by the astronauts to the function of vision. Subjectively, the astronauts did not notice any significant changes. According to their data, in many instances visual acuity even increased. They were able to distinguish landmarks on the ground quite well: rivers, lakes, roads, cities, automobiles, groups of people; they saw the launching of rockets, and at night they could make out main streets. On the water, they could see the tracks of moving vessels at distances of 800 — 1000 km, smoke bomb signals could be seen at distances of 640 km (Cooper, 1963; O'Lone, 1965; Berry, 1970 a, 1971 a).

A number of suggestions have been made with respect to the psychophysiological mechanisms of this phenomenon. A. A. Leonov and V. V. Lebedev (1971) report that the astronauts developed illusory sensations of recognition due to the euphoria caused by reduced impulsation from the gravity and propriorecep-tors during weightlessness. In the opinion of White (1966), the increased visual acuity during weightlessness was caused by a speeding up of the physiological tremor of the eyeballs. The view of Yu. P. Petrov is the most likely one (1969); he feels that the high resolving power of vision in the astronauts may be due to several factors: the initial very high visual acuity and differentiation of objects on the basis of secondary features, i.e., "guessing" objects. For example, when asked to distinguish the track of a vessel in the form of an acute angle in the open sea, the astronaut saw the ship as well.

In all of their reports, the astronauts as a rule reported on the wide range of colors that they saw during flight while looking at terrestrial objects and at the sky. However, there are certain differences in the descriptions. The members of the Apollo 10 crew saw the surface of the Moon to be colored primarily brown. Borman, the commander of Apollo 8, said that it was grey, and so forth. Hence, color perception is not the same in space and on the Earth. An understanding of its mechanisms requires further study and probably has to do not only with the charac- /8
teristics of physiology of vision, but also with the objects and the conditions of illumination of the object at the time of observation.

It was also interesting to consider the statements of the astronauts about how they observed flashes of light during the flight (bands, points) at a frequency of one flash every two minutes, both with the eyes open and closed. Data indicating that the flashes were caused by the influence of weightlessness are nonexistent. The mechanism of this phenomenon is still unclear. However, the opinions of researchers tend more toward the view that the flashes (photopsia) are produced by an external source of radiation, evidently of cosmic origin (White, et al., 1971).

During the flights of the Gemini and Apollo, data were also collected on the nature of the movements of the astronauts under conditions of altered gravitation. It was found that movements of the astronauts under weightless conditions were largely governed by external conditions. They were facilitated if they were carried out within the limits of an area of limited volume (for example, the cabin of a spacecraft). Movements were carried out with slight effort and frequently resembled swimming. Such movements as turning could be carried out in any plane without difficulty. The accuracy of the movement increases the possibility of the astronaut coming in contact with the walls of the cabin. Berry (1971 a) considers it necessary to take these circumstances into account in solving the problem of determining optimum dimensions of spacecraft cabins. Movements became more difficult when the astronauts made EVA maneuvers. After the spacewalks of the Gemini 9, 10, and 11 astronauts, it became clear that they used up a great deal of energy holding their bodies in a certain posture. It was necessary somehow to fasten them and their tools to the workplace. This was taken into account later on in preparations for the Gemini 12 and Apollo flights. As we pointed out earlier, the American astronauts also used manual jet devices for moving around under weightless conditions. Experience has shown that they are effective, but also required a certain degree of technical improvement. Considerable interest surrounds the data on movement on the surface of the Moon. E. Aldrin (Apollo 11) tested various methods, in particular, "kangaroo jumps," leaping from one foot to the other. He experienced difficulty in maintaining his balance while doing this, finding it difficult to keep from falling forward. The most advantageous method was found to be normal walking. C. Conrad and A. Bean (Apollo 12) also found it easy to move around on the surface, despite the dust; they frequently made jumps of 1.2 m ("giraffe runs," resembling slow-motion movies). The same method of moving around was most frequently used by the crew members of the Apollo 15, 16, and 17.

Prior to the first space flights, it was feared that disorientation would arise under weightless conditions. According to the data of the American researchers, these dangers turned out to be false (Berry, 1971 a). No disorientation was experienced, while in the spacecraft cabin, during spacewalks, or on the lunar surface. In evaluating this phenomenon, it is still necessary to keep in mind that three astronauts in the Apollo program suffered illusions of inverted vision in space. It was found that the Gemini 4 astronauts, when they approached a target, noticed themselves in error in visual evaluation of distance by a factor of 4 — 5. The same thing occurred on the surface of the Moon. The lack of landmarks and changes in the nature of the relief depending on the height of the Sun considerably complicated determination of distances. According to the data of the Apollo 7 crew members, during orientation in space, the Earth's horizon could not be used as a reference line. All of this unquestionably causes deterioration of spatial orientation in man when he is exposed to the unusual conditions of space flight.

As we can see from the above, astronauts under weightless conditions undergo a number of unpleasant sensations which affect their psychosensory sensations, the nature of their orientation in space and their movements in it. Unquestionably, all of this /10 necessarily has an effect on the level of their working capacity. A direct answer to this question can be obtained from an analysis of the execution of the program of the flight experiments, particularly during the spacewalks of the astronauts, while carrying operations involving rendezvous and docking of satellites with space targets, in carrying out programs of scientific experiments, and during EVA on the Moon.

The Gemini astronauts, during their spacewalks, essentially carried out all of the tasks with a few minor exceptions (Table 1). The EVA of the astronauts was made more and more complex, and the time spent outside increased. They worked with motion picture cameras and traps for meteor particles; they maneuvered around on a tether and used a jet device; they linked the satellite to the Agena rocket with a cable and so forth (Table 1). In all of these operations, there were no significant changes involving vitally important systems, although the pulse and respiration varied within considerable limits. At certain stages, there was a speeding up of the pulse, as well as an increase of /11 energy consumption that was significant (up to 860 kcal/hour), resulting in profuse sweating, excessive accumulation of heat and phenomena of fatigue (Berry, 1969, 1970 a, 1971 a; Chatelier, Jibert, 1969). It was found that the forces expended in carrying out various operations in deep space are considerably in excess of those which occur as the result of terrestrial experiments. In the opinion of Wagner (1971), carrying out test tasks in deep space requires 100% more time than is needed under terrestrial conditions. The principal reason for the high energy expenditure is the need to maintain the body in a given posture in space.

The complication of the tasks of orbital flights, primarily rendezvous with other craft or rockets, docking with them, and making a transition to a different orbit — all of this has considerably complicated the operator duties of the crew members.

TABLE 1

SPACEWALKS BY GEMINI ASTRONAUTS AND WORK OPERATIONS CARRIED OUT UNDER THESE CONDITIONS

Spacecraft	Astronaut making spacewalk	Duration of exposure to deep space conditions, minutes	Principal operations carried out during spacewalk	Reasons for failure to complete tasks and details of activity
Gemini 4	E. White	20	Installation of motion picture camera on the hull of the satellite, movement in space by means of manual jet device, photography	Orientation not lost during EVA. Expressed recommendation for improving attachment to workplace or small objects needed for work.
Gemini 9	E. Cernan	125	Installation of motion picture camera and reflectors on hull, removal of holder with meteorite particle traps, movement along hull, maneuvering with a lanyard, testing jet device for moving around (35 separate operations) and its attachment to the spacesuit.	Experiment for moving around in space by means of the AMI device not carried out due to fogging of the window of the helmet, deterioration of radio communication with spacecraft and problems with the device. Moving along the hull of the satellite in deep space facilitated by coverings of adhesive material, called Valcro. In the opinion of Cernan, the accomplishment of the operations required 4 — 5 times more effort than on Earth. Heat loss (250 — 500 kcal/hr) much greater than calculated values.
Gemini 10	M. Collins	38	Maneuvering by means of manual jet device, photography, removal of holders with meteorite particles	Duration of EVA reduced due to excess use of fuel in spacecraft stabilization systems. Moving around in space without handles or

TABLE 1
(CONTINUED)

Spacecraft	Astronaut making spacewalk	Duration of exposure to deep space conditions, minutes	Principal operations carried out during spacewalk	Reasons for failure to complete tasks and details of activity
Gemini 10 (continued)			from the orbiting rocket "Agena-8."	other grips was difficult. Moving around by holding on to the lanyard was more difficult than with the use of the jet device.
Gemini 11	R. Gordon	44	Joining the satellite and the "Agena D" rocket with a line 30 meters long, removal of containers with nuclear emulsions from the hull.	EVA cut short due to excessive perspiration.
Gemini 12	E. Aldrin	130	Joining the satellite and the rocket by a cable, installing a holder with traps, replacing the film in the motion picture camera, operations on the "work areas": (a) removal from the satellite hull of strips of various lengths made of adhesive material, known as Velcro, and reattachment; (b) winding a cable on hooks of various sizes; (c) plugging and unplugging electrical connections	"Chocks" attached to the legs were used for attaching the astronauts to the workplace, as well as loops and hooks; special "clips" that could be attached to Velcro material on the housing of the satellite were used for moving around.

TABLE 1
(CONTINUED)

Spacecraft	Astronaut making spacewalk	Duration of exposure to deep space conditions, minutes	Principal operations carried out during spacewalk	Reasons for failure to complete tasks and details of activity
Gemini 12	(continued)		and tubing; (d) cutting multiconductor cables with cutters; (e) loosening and tightening two bolts with a wrench.	

Nevertheless, the Gemini astronauts coped with these problems fully (Table 2). It is clear from an analysis of the table that the experiments that were not performed on Gemini 5 and 11 were abandoned for technical reasons.

The Gemini program was characterized by a large volume of scientific experiments: medical-biological (9), physical-technical (64) and those that were of practical military significance (16). As we can see from Table 3, some of the experiments were not performed by the astronauts, but as the analysis shows, this was not due to a decrease in working capacity but for other reasons: failure of technical devices, problems with the laboratory equipment, shortcomings of the research program, and so on.

In analyzing the Apollo program, we are also struck by the fact that, during the EVA of the astronauts and during the transition to lunar orbit and back again, they carried out all the tasks with one exception. It was only during the Apollo 9 flight that astronaut R. Schweikart was unable to carry out the EVA and spacewalk fully, due to symptoms of incipient motion sickness.

Particular interest with respect to evaluation of the work capacity is provided by data on the activity of astronauts on the lunar surface. As we know, the first man on the Moon, who landed at 2 hours 56 minutes and 20 seconds on the 21st of July, 1969, was N. Armstrong, followed by E. Aldrin. For two hours and ten minutes, the astronauts carried out a great deal of work, erecting television cameras, reflectors, and a seismometer on the surface of the Moon, setting up meteor traps, collecting samples of lunar rock, testing out various methods of moving around on the Moon, and a number of other operations. As we mentioned earlier, the /12
nature of the changes and the physiological parameters were sufficiently adequate for these unusual conditions. In addition,

TABLE 2

EXPERIMENTS INVOLVING RENDEZVOUS AND DOCKING OF THE SPACECRAFT "GEMINI" IN ORBIT WITH TARGETS AND SUCCESS IN ACCOMPLISHMENT

Name of target	Spacecraft	Success achieved
Second stage of Titan II Carrier Rocket	Gemini 4	The problem was one of rendezvous with the rocket. The experiment was unsuccessful. It was found that the astronaut, guided by the satellite, made mistakes in visual evaluation of the distance, sometimes by a factor of 5.
IEP apparatus	Gemini 5	Problem of rendezvous from a distance of 10 km, approach to the target to a distance of 30 m. The experiment was not carried out due to failure of the fuel cells.
Previously launched satellite Gemini VII	Gemini 6	The problem of rendezvous with the satellite arose. The experiment was carried out. As the result of nine maneuvers, the Gemini 6 spacecraft rendezvoused with the Gemini 7 at a distance of 36 m. The group flight lasted 5-1/2 hours while the distance between them was 1 — 30 m.
Second stage of Titan II Carrier Rocket	Gemini 7	The problem was one of rendezvous with the rocket immediately after separation of the satellite. The experiments were carried out. Flight took place jointly with the second stage at a distance of 15 — 18 m.
Agena-D Rocket	Gemini 8	The problem of rendezvous and docking was handled. The experiment was carried out. Nine maneuvers were made, with approach to 45 m, then docking.
ADTA	Gemini 9	Problem of rendezvous and docking. Experiment not carried out. No docking because of failure of technical elements.
Agena-D Rocket	Gemini 10	Problem of docking with the rocket and then shifting to a new orbit. Experiment carried out.

TABLE 2
(CONTINUED)

Name of target	Spacecraft	Success achieved
Agena-D Rocket	Gemini 11	Same as Gemini 10.
Agena-D Rocket	Gemini 12	Problems of approach and docking. Experiment carried out. The onboard radar failed. Rendezvous and docking (twice) carried out manually. Astronauts took turns, using the satellite for guidance.

during their stay on the Moon, they carried out a careful check of the metabolic parameters on the basis of an analysis of the pulse rate, the rate of oxygen consumption and the differences in the temperature of the water entering and leaving the water-cooling system (Berry 1970). The most accurate methods of evaluation were the latter two. They not only provided analogous results, but also provided a good reflection of the physical activity of the astronauts, recorded by means of telemetry.

Figure 1 shows the actual and calculated estimates of energy consumption in carrying out work on the Moon. On the average, the energy consumption of the Apollo 11 astronauts varied between 226.0 and 300.0 kcal/hr, sometimes reaching maximum values (above 600.0 kcal/hour). When we analyze the following EVA of the Apollo 12, 14, and 15, and 16 astronauts, we are struck by the constantly rising volume of research, prolongation of time spent on the lunar surface, and the increase in the amount of lunar rock collected by the astronauts. Nevertheless, White, et al. (1971), observed that the energy consumption associated with the EVA on the Moon decreased. Thus, the energy consumption of astronaut A. Shepard was 210 kcal/hr, while that for E. Mitchell was 220 kcal/hr. They explained this by the correctness of the

TABLE 3

DATA ON PERFORMANCE OF EXPERIMENTS ABOARD GEMINI SPACECRAFT

Experiment	Data on accomplishment (in numerator), partial or complete failure to execute (in the denominator) of the Gemini spacecraft						
	III.IV	V VI	VII	VIII	IX	X	XI	XII
Medical-biological (M1 — M9)	$\frac{\text{—3/M—3, M—4, M—6/}}{0}$	$\frac{\text{2/M—1,— M—6/}}{\text{3/M—3, M—4, M—9/}}$	8/all with exception of (M-2)/0	$\frac{0}{\text{1/M—5/}}$	$\frac{0}{\text{1/M—5/}}$	—	—	—
Physical-technical S1 — S51, MSC-1 — MSC-12, T1	$\frac{2}{1}$ $\frac{6}{0}$	$\frac{5}{0}$ $\frac{0}{2}$	$\frac{6}{1}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{4}{5}$	$\frac{2}{7}$	$\frac{10}{0}$
Applied military	— $\frac{2}{0}$	$\frac{6}{0}$ $\frac{1}{0}$	$\frac{4}{1}$	$\frac{0}{4}$	$\frac{0}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{2}{0}$

planning of the work to be done on the Moon and the training of the astronauts themselves. Special attention should be paid to the results of the Apollo 15 flight (Berry 1971 a; Tiziou, 1971). It was during this flight that the NASA scientists noted a slow-down of the readaptation to terrestrial conditions due to over-fatigue on the part of the astronauts. As was pointed out earlier, there was a change in the rhythm of cardiac contractions during the flight (D. Scott, D. Irwin) and symptoms of motion sickness (D. Irwin). In the opinion of Berry, these symptoms had to do /13
with overfatigue due to the considerable workload of the astronauts and he felt that it was necessary to make some changes in the work schedule of subsequent space flights (Buldan, 1971).

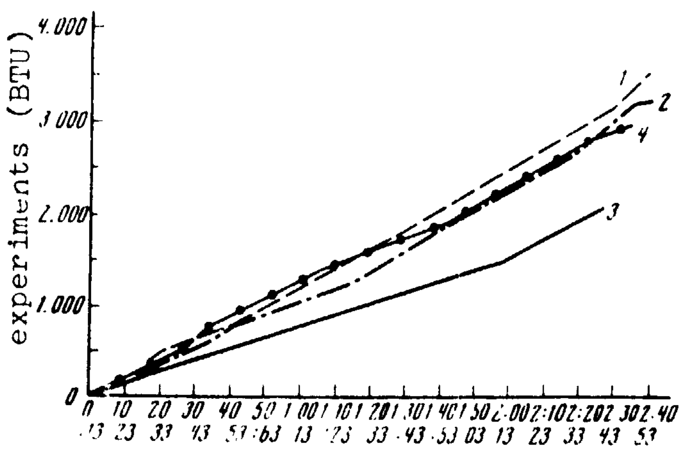


Figure 1. Preliminary and actual estimates of energy consumption in carrying out working operations on the Moon by the spacecraft commander and lunar module pilot of the Apollo 11.

1- calculated data for spacecraft commander; 2- calculated data for lunar module pilot; 3- actual energy consumption by spacecraft commander; 4- actual energy consumption by lunar module pilot; upper row of figures- time from the moment of depressurization of the lunar module (minutes); lower row of figures- local time aboard the satellite (minutes); BTU- British thermal units; 1 BTU = 0.252 kcal.

The highest level of working capacity of the astronauts was seen during the dramatic flight of the Apollo 13, when an accident took place on the way to the Moon — an oxygen tank exploded. The astronauts were forced to use only the limited supplies of oxygen available from the lunar module, to combat the accumulation of excess CO_2 in the air, and to endure prolonged periods of longitudinal and transverse oscillation, apparently due to the escape of gas from the craft (Lomonaco, 1970). These oscillations, combined with weightlessness, promoted the activation of vestibular reactions which caused deterioration of the psychophysiological state of the astronauts. After 134 hours, they felt profound fatigue and were forced to take Dexedrine tablets (a stimulant). Nevertheless, they accurately and reliably carried out all of the operations required for splashdown.

The working capacity of the astronauts was also evaluated on the basis of the manner in which they carried out measured physical exercise before and after flight. For this purpose, in most cases a bicycle ergometer was used which was capable of exerting a constant working load which gradually rose as the pulse rate reached 120, 140, 160, and 180 beats/min. In addition to the pulse, another indicator of the tolerance was data on oxygen consumption, CO_2 output, the level of the minute volume of the blood, the blood pressure, and respiration rate (Dietlein, 1970; White, et al., 1971). As it turned out, following prolonged space flights aboard the Gemini craft, their crews noticed a slight deterioration of their physical working capacity. The same relationship was observed in studying the Apollo astronauts. Thus, at a frequency of 120 beats/minute during bicycle ergometer tests of the Apollo 7, 8, and 9 astronauts, 8 of the 9 men showed a decrease in oxygen consumption. The degree of change was less at higher frequencies of cardiac contraction. To illustrate this, Figures 2 and 3 present the results of an investigation of the Apollo 7 and 10 astronauts. Usually, but not always, recovery of preflight levels took place an average of 36 hours afterward (Johnson, 1971; Berry, 1971 a). The exception we noted above was the result of a test of the Apollo 15 astronauts. Recovery of working capacity at various levels of measured stress took place in them long after the 50-hour period required (for example) by the Apollo 14 crew members for this purpose. According to the data of Soviet researchers (Yetrmin, et al., 1970; Barer, et al. 1972), the energy expenditure by man under conditions of altered (reduced) gravitation also decreases, as was clearly shown in a number of experiments involving simulation of these conditions. /14

<u>Prevention of the harmful effects of spaceflight factors on the human organism</u>. In the course of carrying out the space program in the Gemini and Apollo series, a certain amount of attention was paid to prevention of unfavorable effects of space

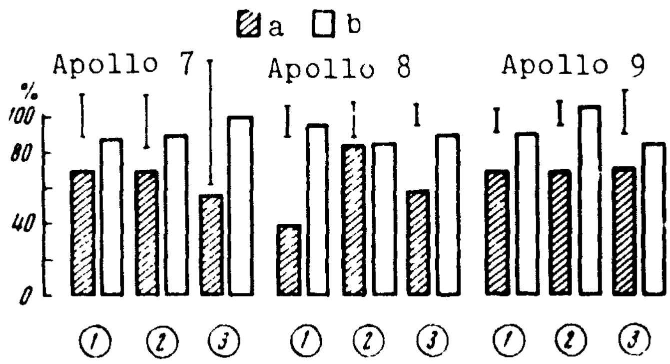
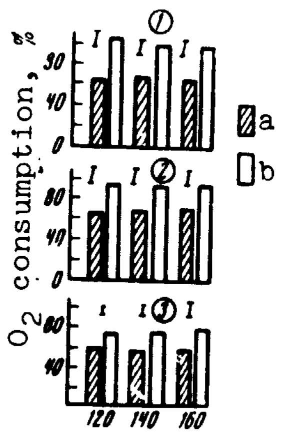


Figure 2. Change in level of oxygen consumption by several astronauts in the Apollo program with frequency of pulse rate of 120 beats/minute during postflight examination (in % of preflight data, taken as 100%).

1- spacecraft commander; 2- command module pilot; 3- lunar module pilot; I- range of changes in preflight studies; a- results of examination immediately after the flight; b- results of examination 24 hours after the flight.

flight. Work continued on further improvement of the gas environment in which the astronauts lived, as well as the food systems, work schedule and rest, and so forth. Thus, the use aboard the Apollo of a two-gas respiratory mixture (O_2 and N_2) with a small amount of nitrogen considerably reduced the decrease in volume of erythrocyte mass which was noticed earlier in the Gemini flights. Including substances in food rations which contain calcium also promoted an improvement in the mineral metabolism as a whole in the astronauts (Berry, 1969, 1970 a, 1971 a; Dietlein, 1970, etc.). A positive effect was achieved by including potassium in the food ration of the Apollo 16 and 17 astronauts in order to prevent cardiac arrhythmia. These measures, aimed at reducing the harmful effects of flight factors and especially weightlessness, improved not only the individual parameters but the general health of the astronauts and their working capacity.



y, pulse rate, beats/minute

Figure 3. Use of oxygen during a work period on the bicycle ergometer by the astronauts of the Apollo 10 crew at a pulse rate of 120, 140, and 160 beats/minute (in % of preflight data, taken as 100%).

1- spacecraft commander; 2- command module pilot; 3- lunar module pilot; I- range of variation in the results of preflight examination; a- examination on splashdown day; b- one day after splashdown.

Considerable attention was devoted in the medical evaluation of the Gemini and Apollo flights to the organization of the work, rest, and sleep schedule of the astronauts (Berry, 1969, 1970 a, 1971 a; Dietlein, 1970; Aschoff, 1971, et al.). As we know, the normal work day is adjusted to a 24-hour cycle: 8 hours for work, 8 hours for rest, and 8 hours for sleep. Investigators showed that a similar ratio was quite stable and could be retained under various spaceflight conditions. Foreign researchers (Berry, 1967, 1971 a; Aschoff, 1971, and others), in organizing the work and rest of the astronauts, tried on each flight to take this feature more fully into account and to achieve the very highest level of working capacity. While during the first Gemini flight only scant attention was devoted to this problem, by the Gemini 7 flight, the order of the day had already been planned out so that the astronauts could sleep during hours that corresponded to night on Earth. Attention was also devoted to the optimum arrangement of the periods of work and rest of the astronauts, particularly while working in outer space. Increasing the number of astronauts aboard the Apollo flights and the desire to have a constant watch by one astronaut meant that the "work-rest-sleep" cycle aboard the Apollo 7 was nearly unregulated and the order of the day of the Apollo 8 crew was far from complete. /15

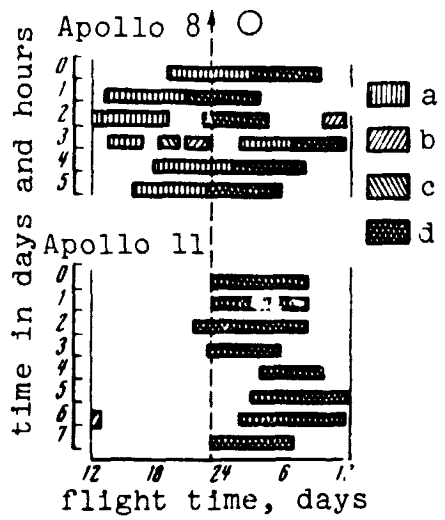


Figure 4. Sleeping schedule for the crew members of the Apollo 8 and Apollo 11 spacecraft.

1- time of going to sleep at Cape Kennedy; a- time of sleep of spacecraft commander; b- time of sleep of command module pilot (CMP); c- time of sleep of lunar module pilot (LMP); d- time of joint sleep by the CMP and LMP aboard the Apollo 8 and the entire crew aboard the Apollo 11.

The astronauts disturbed one another, both in doing work and during sleep. The change in periods of work and rest was irregular and differed markedly from the preflight schedule. The crew members reported feeling badly during the first three days of the flight. One fell asleep on watch; another was forced to take stimulant tablets. They had to give up the idea of a constant watch; beginning with the Apollo 9 flight, all the astronauts worked and slept at the same time.

Figure 4 shows the order of the day for the Apollo 8 and 11 astronauts for the sake of comparison.

When the periods of rest resembled terrestrial conditions, complaints decreased and working capacity rose. Several Soviet researchers have come to the same conclusion (Bodrov, Muzalevskiy, 1972, et al.). In laboratory experiments, the considerably important physiological aspects of "joint" schedules was shown, in which the members of the crew sleep 8 hours continuously during the period corresponding to night on Earth. It seems that this solution of the problem cannot be considered final. In particular, it becomes unacceptable if there is a possibility of the development of an emergency situation during the time the astronauts are sleeping, when rapid and accurate movements are expected of the crew members. Seminara and Shavelson (1969) in their laboratory experiments tried to evaluate the working capacity of the spacecraft crew following sudden awakening and found that the less time required to carry out the task, the more markedly the influence of sleepiness affected it. For example, shutting off the button of an alarm signal, i.e., a very short action, took 360% more time after sleep than it did during wakeful conditions: in the case of a more prolonged operation (putting on a spacesuit), the time increased only 12.6%. From an analysis of American programs, it is clear that studies still have not solved finally the problem of work, sleep, and rest during the period of work on the Moon. The lunar module is too noisy; the climate of the space inside the suit is far from optimum. The members of the Apollo 14, 15, and 16 crews complained that they rested poorly in the lunar module (Berry 1971 a). American researchers feel that it is necessary to do more work on improving the living conditions of the astronauts using the schedule of 12 hours for work, 8 hours for sleep, and 4 hours for rest.

The schedule for preventing cardiovascular problems during flight involved testing of special pneumatic cuffs which the astronauts wore on their wrists, and an automatic device provided for periodic inflation of the cuffs to a pressure of 80 mm Hg in 2 minutes at 4-minute intervals. Although this experiment, which was planned for the Gemini 5 and 7 flights, was not carried out /16
fully on any one flight (due to technical problems), the American specialists did not have a very high opinion of the preventive significance of the cuffs. In their opinion, they had no important influence on circulation.

In the opinion of many specialists, the effective method of preventing unfavorable reactions is to equip the spacecraft with artificial gravitation (Yuganov, Pavlov, 1967; Yuganov, Yemel'yanov, Genin, 1969; Genin, Pestov, 1971; Gualtierotti, 1969; Green, et al., 1970; Nieto, 1970; Grahmann, 1971; Lange, Belleville, 1971; Young, 1971, et al.). While carrying out the program of the Gemini and Apollo flights, a great deal of interesting data was collected. By performing an experiment which included linking the Gemini and the Agena-D rocket by a cable (Table 1), the possibility of producing artificial gravitation in such systems was demonstrated in practice.

Additional and very important information was obtained in flights in the Apollo program, when the crew members were subjected to partial weightlessness on the lunar surface. On each flight, it was possible to compare the influence of this factor on the course of the psychophysiological reactions caused by the state of weightlessness. The tendency developed that those persons who were subjected to the influence of lunar gravitation showed more moderate changes than those who spent all their time exposed to weightlessness (Berry, 1970 a, 1971 a). For the sake of illustration, we can use the results of the study of the Apollo 14 crew members (Table 4). The only exception was the results of the Apollo 15 flight (Berry, 1971 a). In the two crew members who worked on the Moon, there was a greater decrease in working capacity than there was in the command module pilot. It was suggested that this was due to overfatigue of the astronauts due to the large amount of work that they performed on the lunar surface. This fact, as well as certain other data, constituted the basis for performance of further tests in this direction.

TABLE 4

COMPARISON OF PRE- AND POSTFLIGHT DATA FROM EXAMINATIONS OF CREW MEMBERS ABOARD THE APOLLO 14

Result of exposure	Constant influence of weightlessness	Exposure to 1/6 gravity conditions	
	Command module pilot	Spacecraft commander	Lunar module pilot
Weight loss, kg	-5.4	+0.45	-0.45
Decrease in orthostatic stability	significant	minimum	minimum
Change, %:			
erythrocyte mass	-9	-4	-2
plasma volume	-10	+1	unchanged
total water volume	-18	-2	-2
intracellular fluid	-27	-3	-3
Working capacity (O_2 consumption, systolic blood pressure)	significant decrease	unchanged	slight decrease

The problem of artificial gravitation is also closely linked to motion sickness. Graybiel (1971) writes in his paper that, if artificial weight is produced by means of rotation of a manned portion of a spacecraft, the rapid transition of man between the rotating and the nonrotating part obviously would be the basis for the development of serious problems of a vestibular nature. For simulation of these conditions, the author mentions some ways of overcoming them: optimum training and medicinal therapy. /17

Special attention should be given to the work of Gualtierotti (1969), who held to a firm opinion about the need for developing artificial gravitation for long flights. In view of the fact that it can be produced by spinning spacecraft, he pointed out an undesirable side effect — the development of motion sickness due to the action of the Coriolis forces. In his opinion, there is still another way — using nonspecific stimulation of stato-receptors in the inner ear. In experiments on frogs, he studied the influence of vibrations on the statoreceptors and concluded that vibrations of a constant intensity and constant direction produced effects that were basically analogous to the phenomena which were observed under the influence of linear accelerations.

The principal medical-biological results that were obtained in the course of the performance of the flights in the Gemini and Apollo spacecraft showed that, under the influence of spaceflight factors, the human organism experiences the following: moderate decrease in weight, lack of training of the cardiovascular system, which develops with a decrease in the orthostatic resistance and a number of other changes; a decrease in the density of bone tissues; slight losses of calcium, iron, and other minerals, as well as nitrogen from the muscles; a slight decrease in the erythrocyte mass; a slight drop in working capacity, greater energy consumption in carrying out work in spacewalks and moderate energy consumption under conditions on the lunar surface; the development of a state of motion sickness under weightless conditions. Berry (1969, 1970 a, 1971 a) considers these changes separate branches of a process of adaptation of the organism to stress factors in space flight (Table 5, Diagram 1). As we can see from his hypothesis, the direct reaction of the organism to a shift to weightless conditions is a redistribution of the basic mass of circulating blood. The filling of the right auricle with blood is accompanied by a reaction aimed at reduction of the total amount of fluid in the organism through increased diuresis. This process is regulated by the decrease in the level of the antidiuretic hormone and a drop in the production of aldosterone. There is also an expulsion of water, sodium, and potassium from the organism by the kidneys, and a drop in body weight. The accompanying decrease in plasma volume leads to a

DIAGRAM 1

PHASES OF THE PROCESS OF ADAPTATION OF THE ORGANISM TO WEIGHTLESSNESS

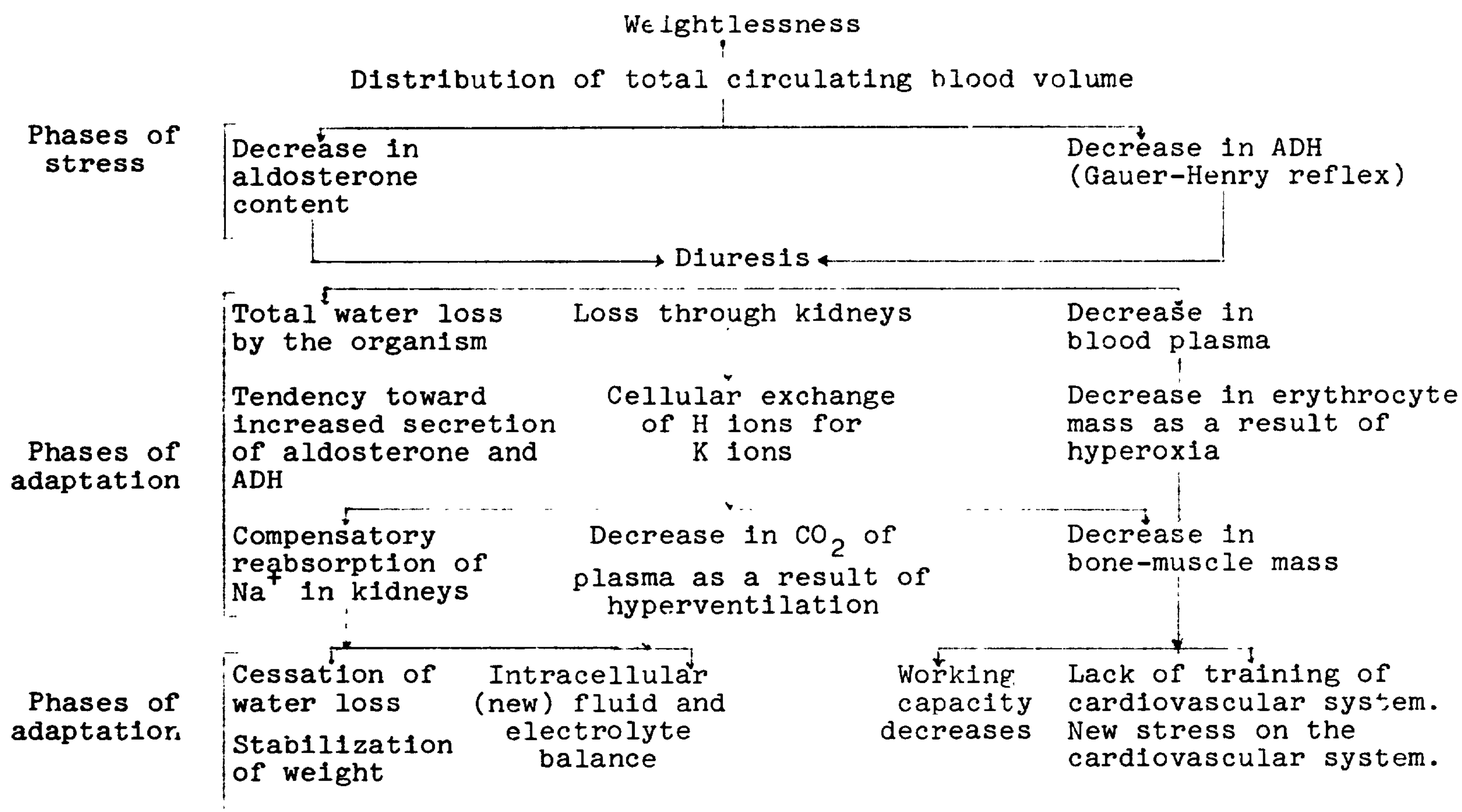


TABLE 5

PROCESSES OF ADAPTATION OF THE HUMAN ORGANISM TO WEIGHTLESSNESS (HYPOTHESIS)

Reactions of the organism		
Transition to weightless conditions. Redistribution of the volume of circulating blood.	→	Reactions of the organism aimed at reducing volume. Decrease in the level of antidiuretic hormone and formation of aldosterone.
Loss of water, sodium, potassium (decrease in body weight)	→	Decrease in plasma volume. Increase in aldosterone production.
Increase in sodium retention. Potassium excretion continues. Cellular acidosis and alkalosis of extracellular fluid takes place.	→	Intracellular exchange of potassium and hydrogen ions. Decrease in bone density, as well as density of the tissues, muscle mass, potassium content in the muscle cells.
Respiratory and renal compensation. Stabilization of body weight.	→	Stabilization of the new volume of circulating blood and water-salt and electrolyte balance.

reverse modification of the initial decrease in aldosterone. The organism undergoes disruption of the water-salt balance; against this background, there is a retention of sodium and continuation of potassium excretion. The losses of intracellular fluid and the excretion of potassium from the organism cause cellular acidosis with mild (compensated) hypokaliemic alkalosis of extracellular fluid.

It is suggested that the reactions of the organism to a decrease in the total potassium content are manifested by the excretion of potassium from the cells and the passage of hydrogen ions into them. The shortage of potassium has to do with a decrease in the density of the bone tissue and muscle mass. It is possible that the decrease in potassium content in the cells /19 of the cardiac muscle is accompanied by an increase in its excitability and tendency toward arrhythmia.

In the latter phase of adaptation, the hyperacidity of the cells stimulates the activity of the respiratory system, so that there is a decrease in the CO_2 content in the plasma due to an increase in pulmonary ventilation. Renal compensation begins when the kidney tubules begin to reabsorb potassium. It is at this time that the entire body is stabilized. This portion of the complex process of the organism's adaptation is complete. The new state of equilibrium establishes the optimum total volume of circulating blood or "new stress" on the cardiovascular system and the new level of electrolyte and water-salt balance.

The author of this hypothesis, Berry, considers it far from perfect. In his opinion, it will be improved and added to. The hypothesis makes it possible to follow the course of the changes that occur in the human organism under the influence of unfavorable environmental factors, with the resources of the organism not being exhausted in overcoming them.

He (Berry, 1971 a) feels that there is every reason now to carry out flights lasting a very long time. For this purpose, the USA is going forward with its flights; in 1973 the Skylab flights lasting 28 and 56 days took place. During the flights, the U.S. scientists continued their research (Diagram 2).

As we can see, most of the researchers' attention was concentrated on those systems and functions of the human organisms which are most subject to changes under weightless conditions.

DIAGRAM 2

MEDICAL-BIOLOGICAL EXPERIMENTS ABOARD SKYLAB ORBITING STATION

Man

Behavioral reactions: Study of time and motion characteristics

Problems of nutrition and bone-muscular apparatus: salt balance, densitometry of the bones, biological analysis of fluids in the organism, study of the feces.

Hematology and immunology: cytogenetic studies of the blood, human immunity (experiments in vitro), blood volume and survival time of erythrocytes, metabolism of erythrocytes, special hematologic effect, single human cell.

Neurophysiology: function of vestibular apparatus; monitoring of sleep

Pulmonary function and energy exchange: metabolic activity, measurement of body mass.

Cardiovascular system, negative pressure on lower half of the body (pre- and postflight studies), negative pressure on lower half of the body during flight, vector cardiogram.

Hygienic and general biological problems: study of the environment (living quarters), analysis of aerosols in the environment and monitoring of the radiation level, study of circadian biorhythms in the pocket mouse and fruit fly.

REFERENCES

Baranovskiy, V. V., M. D. Yemel'yanov, and A. G. Kuznitsov. Zh. vyssh. nervn. deyatsti., Vol. 12, No. 6, 1962, p. 1001.

Barer, A. S., N. K. Gnoyevaya, and A. N. Serebryakov. In the collection: Kosmicheskaya biologiya i aviakosmicheskaya meditsina (Space Biology and Aerospace Medicine). Moscow Kaluga, Vol. 1, 1972, p. 55.

Bodrov, V. A., and A. Ye. Muzalevskiy. In the collection: Kosmicheskaya biologiya i aviakosmicheskaya meditsina (Space Biology and Aerospace Medicine), Moscow Kaluga, Vol. 2, 1972, p. 96.

Gazenko, O. G., and A. A. Gyurdzhian. Problemy kosmicheskoy biologii (Problems of Space Biology), Moscow, "Nauka" Press, Vol. 6, 1967, p. 22.

Genin, A. M. Kosmicheskiye issledovaniya (Space Research). Moscow, "Nauka" Press, Vol. 7, No. 5, 1969, p. 797.

Genin, A. M., and I. D. Pestov. Fourth International Symposium Entitled "Man in Space," Yerevan, October 1 - 5, 1971.

Yemel'yanov, M. D. Problemy kosmicheskoy meditsiny (Problems of Space Medicine). Moscow, 1966, p. 164.

Yemel'yanov, M. D., and Ye. M. Yuganov. "The Problem of the Interaction Between Analysors in Space Flight." Paper delivered at the International Symposium on the Basic Problems of Human Life in Space, Paris, 1969.

Yeremin, A. V., V. I. Stepantsov, V. I. Sokolkov, and M. A. Tikhonov. Kosmicheskaya biologiya i meditsina, No. 1, 1970, p. 41.

Kolosov, I. A. Izv. AN SSSR, Ser. biol., No. 5, 1969, p. 736.

Komendantov, G. L., and V. I. Kopanev. Problemy kosmicheskoy biologii (Problems of Space Biology). USSR Academy of Sciences Press, Moscow, Vol. 2, 1962, p. 80.

Leonov, A. A., and V. I. Lebedev. Psikhologicheskiye osobennosti deyatel'nosti kosmonavtov (Psychological Characteristics of the Activity of Cosmonauts), Moscow, "Nauka" Press, 1971.

Molchanov, N. S., T. N. Krupina, V. A. Balandin, A. V. Beregovkin, M. M. Korotayev, N. A. Kuklin, Ye. T. Malyshkin, V. V.

Nistratov, A. S. Panfilov, and V. M. Tolstov. Kosmich. biol. i med., Vol. 4, No. 6, 1970, p. 39.

Pestov, I. D. Problemy kosmicheskoy biologii (Problems of Space Biology), Vol. 4, 1965, p. 535.

Petrov, Yu. P. In the collection: Fiziologiya zreniya v normal'nykh i ekstremal'nykh uslovayakh (The Physiology of Vision in Normal and Extremal Conditions), Leningrad, 1969, p. 124.

Sisakyan, N. M., and V. I. Yazdovskiy (Editors). Pervyye kosmicheskiye polety cheloveka (The First Manned Space Flights). Moscow, USSR Academy of Sciences Press, 1962; Pervyy gruppoviy kosmicheskiy polet (The First Group Space Flight). Moscow, "Nauka" Press, 1964.

Khazen, I. M. Trudy pyatykh chteniy, posvyashchennykh razrabotke nauchnogo naslediya i razvitiyu idey K. E. Tsiolkovskogo (Transactions of Five Lectures Devoted to Developing the Scientific Tradition and the Development of the Ideas of K. E. Tsiolkovskiy). Moscow, 1971, p. 3.

Kilov, K. L. Funktsiya organa ravnovesiya i bolezn' peredvizheniya (Function of the Organ of Equilibrium and Motion Sickness). Leningrad, "Meditsina" Press, 1969.

Yuganov, Ye. M. Problemy kosmicheskoy biologii (Problems of Space Biology), Moscow, "Nauka" Press, Vol. 4, 1965, p. 54.

Yuganov, Ye. M. and M.D. Yemel'yanov, Fourth International Symposium entitled "Man In Space", Yerevan, 1-5 Oct. 1971, 1971.

Yuganov, Ye. M. and V.I. Kopanev, Voyenno-Meditsinskiy Zhurnal, No.1, 1973, p 66.

Yuganov, Ye. M. and G.I. Pavlov, Izvestiya Akademii Nauk SSSR,, Seriya Biol, No. 2, 1967, p 286.

A s c h o f f Y. 1971 The Fourth Internat S. ..posium on Basic Environmental Problems of Man in Space Yerevan, USSR, 1—5 oct. 1971.
B e r r y Ch. A 1967. J. Amer Med Assoc, 201, 86.—1969 - Aerospace Med., 40, 245.— 1970a. Aerospace Med, 41, No 1. 109.- 1970b Aerospace Med, 41, No 5, 500.— 1971a. XXII nd International Astronautical Congress Brussels, Belgium, 25 Sep.— 1971b.
T h o F o u r t h I n t e r n a t i o n a l S y m p o s i u m on Basic Environmental Problems of Man in Space, Ost. 2, Yerevan, USSR
B e r r y Ch. A 1973. Weightlessness. In Bioastronautics Data Book, Second Edition, James F. Parker, Vita R. West, NaSA, Washington, 349.
B u l d a n E. J. 1971 Aviat. Week and Space Technol, 95, 21.
C h a t e l i e r J., J i b e r t A. P. 1969 Rev. Corps Sante Armees Terre, Mer, Air, 10, No 6, 761
C o o p e r J. 1963. Aviat. Week and Space Technol., 79, No. 16, 61.
D i e t l e i n F. 1970. Proc. of Symposium on Hypogravic and Hypodynamic Environments, June 16—18, 1969, French Lick, India. Session 1: Weightlessness Indiana University A-3662, Jan. 1.
G r a y b i e l A. 1968. Presented at the 3-d Intern. Symp. on Basic Envir Prob. of Man in Space, Genewa.— 1971. The Paper Presented at the Fourth International Man in Space Symposium. Yerevan, USSR, 1—5 Oct.
G r e e n J. A., P i l a n d W. M. 1970. AIAA Paper, No. 1329, 7, ill.
G r o h m a n n R. 1971. HNO, 19, No. 2, 50.
G u a l t i e r o t t i T 1969. Proc 8th Int Symp. Space Technol and Sci. Tokyo. 1969. Tokyo, 1193
J o h n s o n R L. 1971. The Fourth International Problems of Man in Space. Yerevan, 1—5 Oct.
J o h n s o n W. H. 1971. J. Laryngol. and Otol.. 85, No. 12, 1246.
L a n g e K. O., B e l l e v i l l e R. E. 1971. AIAA Paper, No. 854, 8.
L o m o n a c o T. 1970. Minerva Med., 61, No. 74, 3910.
M i l l e r E. F., G r a y b i e l A., K e l l o g g R. S., O'D o n n e l l R. D. 1969. Aerospace Med., 40, 862.
N i e t o B. M. 1970. Iberica, 48, No. 93, 86.
O'L o n e. 1965. Aviat. week and Space Technology, 83, No. 9, 51.
S e m i n a r a J., S h a v e l s o n R J. 1969. Aerospace Med., 40, No. 7, 723.
T i z i o u J. 1971. Aviat. mag, No. 558, 60.
W a g n e r B. M. 1971. J. Clin. Pathol., 24, No. 4, 289.
W h i t e W. Y. 1966. Aerospace Med., 4, No. 36, 324.
W h i t e S. C., B e r r y Ch. A., H e s s b e r g R. R. 1971. Paper Presented at the Meeting of Working Group V, COSPAR, Seattle, Washington, June 26.
W u n d e r Ch. 1965. In: Inst. Environment. Sci. Annual Techn. Meet. Proc., Chicago, 593.
W o u n g I. R. 1971. AIAA Paper, No. 870, 4, ill.